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Analogies to Succeed: Applications to Service Design Problems

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Abstract (maximum 150 words)
This study aims to expand current understanding of ideation methods and its transferability from the physical domain (product) to the transactional domain (services). It evaluates the impact of two Design-by-Analogy (DbA) ideation methods (WordTree and SCAMPER) in both, creativity and design fixation management when solving transactional design problems. These results are contrasted with the performance of a non-assisted control scenario. Both DbA methods produced a statistically significant larger number of novel ideas when compared to the control. The SCAMPER method contributes with a large portion of total novel ideas. Counterintuitive results were found for fixation since SCAMPER appears to be a method that promotes both fixation and de-fixation outcomes.

Keywords: Design-by-Analogy, Design Methods, Creativity, Design fixation

1 Introduction

This study explores the impact of two Design-by-Analogy (DbA) approaches, SCAMPER and the WordTree method, on creativity and design fixation when solving transactional design problems. These results are contrasted with the performance of a non-assisted control scenario.

1.1 Analogies in cognition

Analogy is the association of a situation from one domain (source) to another (target) that is possible due to similarity relations or the mapping of representations [1]. Previous studies show a solid relationship between analogical reasoning and the cognitive processes associated with linguistics and semantic memory retrieval [2, 3].

1.2 Semantic memory retrieval

Semantic memory refers to the organization of information in the human mind. It is usually represented as a network of concepts (nodes) that are linked through categories [4, 5, 6]. From this model, a concept will be accessed more easily if the distance (i.e. number of links traversed) shortens, or if multiple paths converge to that specific concept node. General concept nodes tend to be connected to a larger number of nodes, thus becoming hubs in the network. Linking new concepts through hubs increases the probability of being retrieved due to distance reduction [4, 7, 6], a key mechanism to perform analogical reasoning

1.3 Design-by-Analogy Methods

Design-by-Analogy has the premise that a similar solution to a given design problem may exist either in an analogous domain or, at least in part, in an analogous solution, and that it can therefore be extracted or elaborated once the analogy connections between source and target are made.

The available DbA methods have a range of sources for analogical inspirations such as exploring of analogical categories by means of questions [8, 9], finding inspiration in the natural world [10], using biomimetic and bio-inspired concepts [11, 12, 13, 14, 15], developing abstractions of functional models and flows [16, 17, 18], creating design problem re-representation and semantic mappings [19, 20], developing search engines and algorithms to identify potential analogies within digital sources, databases, and repositories [21, 22].

1.4 SCAMPER Method

This method was developed as an attempt to structure, condense and improve Osborn's brainstorming recommendations [23]. SCAMPER ha seven operator categories that may be used to develop solutions to a design problem: (S) Substitute, (C) Combine, (A) Adapt, (M) Modify/Magnify/Minimize, (P) Put to other uses, (E) Eliminate, and (R) Reverse/Rearrange. For each operator category there is a set of questions that, when attempt to be answered, redirects analogical search to solve a problem. For example, if a designer is asked to improve the portability of battery chargers, she may choose (M) Modify. The triggering questions of the Modify category are e.g. What can be modified?, Convert a rotary action to a linear one? How can this approach be altered for the better? These operator questions may lead to new design ideas such as shape shifter device that with a pulling force can expand to place the batteries and with a pushing force reduces it size and make it less bulky.

1.5 WordTree Method

The WordTree method was developed within the engineering domain articulating the concepts of metaphor, analogy, and semantic memory retrieval. WordTree enables design problem re-representation, and detection of potential analogies and analogous domains [19, 24, 25].

The method identifies "key problem descriptors (KPDs)" which can be functional requirements, customer needs, or clarifying descriptions of the design problem. KPDs are then semantically re-represented in a diagram, known as a WordTree, by populating the branches through selected hyperonymy[1] and troponyms[2] extracted from Princeton's WordNet. From this WordTree diagram, potential analogies can be researched and analogous domains explored to discover solutions. The next step consists of developing alternative problem statements, or problem representations. The final step involves another idea generation session, where the results from all previous steps are used to both refine and develop additional concept solutions.

A similar method to WordTree developed within the architecture domain is the Idea Space System (ISS) [20] which is a computational ideation approach that captures design data such as textual descriptions, sketches, and images, and uses this information to generate semantic

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[1] Hyperonymy links to more general concepts.

[2] Troponyms express increasingly specific manners to characterize an event.

associations by means of Princeton's WordNet that are visually displayed to the designer during concept generation.

2 Methods

The study was carried out in two phases and participants worked individually. In phase I, participants used only their intuition and personal experience to generate concepts. A two day period between phases was then provided. In phase II, participants were assigned to a concept generation condition (Figure 1), and the experimental groups were trained in their assigned method. Each group worked in a separate location. During the second phase, all groups continued generating concepts for the same design problem posed in phase I using their assigned concept generation condition.

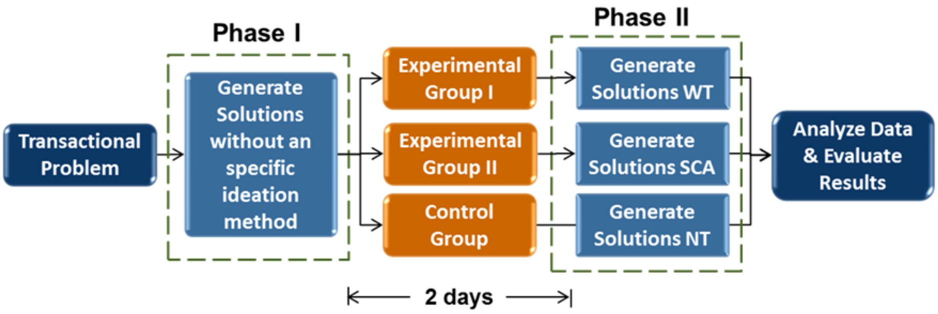

Figure 1. Study design overview

The study involved 97 transactional domain experts from companies in Mexico and Singapore. As shown in Table 1, participants were assigned to one of following three conditions: WordTree (WT), SCAMPER (SCA), or No Technique (NT).

Table 1. Sample size of participants for experimental conditions

Conditions	NT	WT	SCA
Sample Size	36	37	24

A relevant transactional design problem was adopted from a previous study [26] that explored the influence of a design by analogy approach in transactional, service type problems. Participants were asked to generate as many new solutions as possible to a particular financial problem, i.e., "reduce overdue accounts and unpaid credits. Participants were encouraged to do their best to create as many solutions as possible over a 15 minute period for the given design problem.

3 Ideation Metrics

Three ideation metrics were chosen to evaluate the results of the study: (1) quantity of ideation, (2) design fixation, (3) novelty.

3.1 Data setup

The experimental data were organized and coded for post-experiment analysis. The ideas recorded by participants were evaluated by two domain-knowledge expert raters who independently sorted the total 1,788 recorded ideas participants' solutions into bins of distinctive ideas resulting in 148 bins generated by the two raters. To determine inter-rater agreement, Cohen's Kappa [27] was calculated, with a result of 0.78 which is considered an "excellent" level [28]. All disagreements were resolved through discussion, resulting in a final total of 134 distinctive bins.

3.2 Quantity of ideation

Building on existent definitions and procedures to calculate quantity of concepts within the engineering design domain [29, 30, 31, 32], we defined following variables to account for quantity of ideas: (1) Quantity of Total ideas (Q_{Total}), (2) Quantity of Non-Repeated ideas (Q_{NR}), and (3) Quantity of Repeated ideas.

$$Q_{Total} = \sum all\ ideas\ generated = Q_{NR} + Q_R \tag{1}$$

Quantity of total ideas generated is expressed as the summation of all ideas generated (Eq. 1), at different levels, such as in phase (I, II), across experimental groups (WT, SCA, NT), and by each participant. An alternative definition for Q_{Total} is provided as the summation of Quantity of Non-Repeated ideas (Q_{NR}) and Repeated Ideas (Q_R). A repeated idea occurs when a participant states an idea more than once (as a variant or in literal form).

3.3 Design Fixation

Design fixation relates to the inability of designers to develop unique solutions or breadth of solutions to solve design problems, where limitations are caused by: the use of a familiar solution ignoring new or better ones, self-imposing constraints [33], or, as in the case of the present study, through the development of basic variants [34, 35, 36]. We will use the design fixation metric shown in Eq. 2 that we proposed in a previous study [26].

$$Fixation = \frac{Total\ \#\ of\ repeated\ ideas}{Total\ \#\ of\ generated\ ideas} = \frac{Q_R}{Q_{Total}} = \frac{R_W + R_B}{Q_{Total}} \tag{2}$$

There are two sources for repeated ideas in the fixation definition presented in Eq. 2:

- Repeated ideas within a phase (R_W): defined as the summation of all repeated ideas in one phase across all participants that have a frequency (F) greater than 1 as shown in Eq. 3.

  $$R_{W_i} = \sum_{j=1}^{b} \sum_{k=1}^{n} F_{ijk} - 1 \quad \forall\ F_{ijk} > 1 \tag{3}$$

  where F_{ijk}=frequency of repeated ideas for the *ith* phase, *jth* bin, and *kth* participant; i=phase number (1, 2); b= number of bins (134); and n= number of participants. A unit is subtracted from F_{ijk} to maintain accountability of the total ideas generated.

- Repeated ideas between phases (R_B): for bin and participant levels, R_B takes into account all ideas that are repeated in phase II after being generated in phase I.

  $$R_B = \sum_{j=1}^{b} \sum_{k=1}^{n} F_{2jk} \quad \forall\ F_{1jk} > 1\ \ AND\ \ F_{2jk} > 0 \tag{4}$$

  where F_{ijk}=frequency of repeated ideas for the *ith* phase, *jth* bin, and *kth* participant; i=phase number (1, 2); b= number of bins (134); and n= number of participants.

3.4 Novelty

Building upon Jansson and Smith's [34] and Chan's [37] definitions, we define novelty by means of the total quantity of non-repeated ideas (Q_{NR}). For calculation purposes, phase I is considered the design space baseline. Novelty is defined as the design space composed of all ideas (not bins) generated by a participant in phase II that were not generated by any participant in phase I, over the participant's total phase II ideas.

$$\text{Novelty}_{k,l} = \frac{\sum_{j=1}^{b} F_{2jkl} \;\; \forall F_{1jkl}=0 \text{ and } F_{2jkl}>0}{\sum_{j=1}^{b} F_{2jkl}} \quad (5)$$

where F_{ijkl}=frequency of ideas for the ith phase, jth bin, kth participant, and lth group; i=phase number (1, 2); k=participant number (1,…, 97); l=group (WT, SCA, NT); and b=number of bins (134)

4 Results

4.1 Quantity

Q_{Total} corresponds to a total of 1,788 ideas, while Q_{NR} equals a total of 1,230 non-repeated ideas as shown in Table 2.

Table 2. Quantity results break down

	NT (n=36)		Δ%	WT (n=37)		Δ%	SCA (n=24)		Δ%	Total (N=97)		Δ%
	Ph I	Ph II		Ph I	Ph II		Ph I	Ph II		Ph I	Ph II	
Q_{Total}	327	330	-0.01	296	193	0.35	318	324	-0.02	941	847	0.10
Q_{NR}	282	158	0.44	247	141	0.43	224	178	0.21	753	477	0.37
Q_{NR} Average	7.8	4.4	0.44	6.7	3.8	0.43	9.3	7.4	0.20	7.8	4.9	0.37

WT is the only condition where Q_{Total} was reduced from phase I to phase II. After removing repeated ideas, all three evaluated conditions resulted in a reduction in the number of ideas generated in phase II compared to their phase I. SCA produced on average more Q_{NR} in both phases compared to the other two conditions.

Comparing phase I and phase II for each experimental group, a statistical significant difference is found in the quantity of non-repeated ideas for the NT and WT conditions (NT: F=21.87, p-value=0.000; WT: F=17.25, p-value=0.000). In both cases, the quantity of ideas developed during phase II was reduced. The SCA condition showed no statistical significant difference in the quantity of ideas between the phases (F=2.66, p-value=0.110).

4.2 Fixation

Counterintuitive results were found for fixation, as shown in Table 3. The WT condition appears to effectively manage fixation rate compared to the control scenario. SCA and control condition have very similar fixation levels.

Table 3. Fixation results across conditions

	NT (n=36)		WT (n=37)		SCA (n=24)	
	Ph I	Ph II	Ph I	Ph II	Ph I	Ph II
R_W	45	40	49	24	94	79
R_B	0	132	0	28	0	67
$\mathbf{Q_R}$	**45**	**172**	**49**	**52**	**94**	**146**
Q_R Average	1.3	4.8	1.3	1.4	3.9	6.1
Fixation %	**13.8%**	**52.1%**	**16.6%**	**26.9%**	**29.6%**	**45.1%**

ANOVA fixation analysis between experimental conditions in phase I shows a statistical significant difference (F=5.26, p-value=0.007). Tukey's pairwise comparisons show that there is a statistically significant difference between the SCA condition and the other two conditions. Comparing phase I with phase II, statistical significant differences are shown across conditions (SCA: F=13.41, p-value=0.001; WT: F=5.81, p-value=0.019; NT: F=95.34, p-value=0.000). Phase II results for experimental conditions showed a statistical significant difference (F=10.99, p-value=0.000) between WT and the other two conditions.

These results imply that all conditions resulted in fixation, but what is interesting is that a distinctive lower level was achieved with WT condition. The participants that used the SCAMPER method exhibited a very similar fixation level as the control condition.

4.3 Novelty

A total of 15 bins were uniquely generated in phase II, distributed as follows across conditions: NT=1, WT=5, and SCA=9. These 15 bins correspond to a total of 21 non-repeated ideas uniquely generated in phase II (*Novel ideas*). Table 4 presents *Novel ideas* distribution across conditions as well as novelty calculated values as defined by Eq. 5.

Table 4. Novel Ideas and Novelty

NT		WT		SCAMPER	
Novel ideas	Novelty	*Novel ideas*	Novelty	*Novel ideas*	Novelty
2	1.0%	6	3.5%	13	7.1%

After performing an ANOVA, an overall statistically significant difference between the total number of novel ideas generated is found between the conditions (*F*=8.06, *p-value*=0.001). Tukey's pairwise comparisons showed that the SCA condition is statistically different than the other two conditions.

A similar ANOVA result occurred for calculated novelty values across conditions (*F*=4.65, *p-value*= 0.012). Both DbA conditions, SCA and WT, have higher novelty percentages when compared to the control condition. The SCA condition, however, appears to have the most significant contribution of total novel ideas.

5 Discussion and Conclusions

Over the last three decades, industrial practice shows, e.g. an increase of service's share in global economic activities, and design solutions are more often focusing on the combination of services and products. These trends pose a challenge to designers because they need to be able to solve a broader range of design problems, i.e. a pure transactional design problem (service domain), a pure physical design problem (engineering, industrial design and architecture domain), or a product service system design problem (intermediate state that provides solutions involving products and services).

To address the broader range of design problems, the need exists to investigate the cognitive mechanisms behind ideation methods, and evaluate the transferability of ideation methods from physical domains to transactional. Such investigations will aid in our understanding of the effectiveness of current design methods, advancements in design methods, and practical considerations on how to implement ideation methods

For the study explored in this paper, we consider two ideation methods that have been shown to be effective in physical product design. These methods, SCAMPER and WordTree, are both categorized as design-by-analogy. The modality of representation for both methods is quite different. SCAMPER prompts active questions that guide the designer into developing a response for a proposed situation (category). WordTree on the other hand is an open-ended method in the sense that the exploration is not directed by specific set of action prompts, but is enabled instead by designer-driven semantic re-representation of key elements (customer needs, functional requirements, user activities, clarifying descriptions of the design problem, etc) of a design problem. For the experimental results of the study, we observe that despite the prompt used, re-representation is a similar feature of both methods that enables a divergent mind-set (analogy) when developing solutions for a transactional design problem. This result is shown by statistically improved novelty metrics for both methods when compared to a non-assisted condition.

Based on the experimental results, DbA methods enable not only design problem re-representation, but also improve design space exploration and novel idea production when compared to a non-assisted condition. The quantity of non-repeated ideas obtained when participants use SCAMPER is higher than the quantity obtained with WordTree. This result indicates a potentially higher fixation condition for participants using SCAMPER; however, it is interesting to notice the significant impact of both DbA methods in Novelty results, where the non-assisted condition contributes roughly 7% of the number of total novel ideas, the remaining 93% can be attributed to the two DbA methods (WordTree=33% and SCAMPER=60%). The reduction in quantity of non-repeated ideas generated with WordTree compared to SCAMPER may be attributed to the method's relative distinctiveness of analogies created from WordTree compared to SCAMPER.

Experimental results shows that both methods appear to be effective to facilitate analogical reasoning, as shown by the quantity and novelty metric results; however, the fixation results show that participants using WordTree, compared to participants using SCAMPER, perform quite differently. This difference may be due to the guided questioning of the SCAMPER methods that may have a structure closer to our natural process of semantically link concepts in long-term memory.

The individual average quantity of non-repeated ideas for participants using the WordTree method is almost half the quantity for SCAMPER (3.8/7.4=51.4%), but what is more intriguing is that this proportion is almost the same for Novelty (5/9=55.5%, or 3.5/7.1=49.3%).This result means that participants using either method generate proportional levels of quantity and novelty. Perhaps an explanation of the relatively lower level of novelty results of WordTree can be interpreted as the method requiring more non-intuitive work from the users.

Based on these results, the investigated DbA methods, SCAMPER and WordTree, may complement each other. Distinct results in novelty and fixation are created when participants use the methods, where participants using either method outperform a control condition. In the case of SCAMPER, operators enable both refinements of ideas as well as divergent thinking. In the case of WordTree, on the other hand, the semantic representation of the design problem, through diverse a broad range of linguistic terms, enables divergent thinking but a much lower level of refinement.

Overall, both DbA methods explored in this paper appear to significantly improve participants' performance with transactional design problems. This result is consistent with the results reported for DbA methods used to solve physical design problems. Because of this consistency, we may infer that the DbA methods are transferable across a spectrum of design problem types. An important implication of this finding is the potential universal application and implementation of ideation methods, either individually or in a suite of methods, for organizations and designers as they engage the ever-changing landscape of markets and grand challenges facing society.

Acknowledgement

Acknowledgement(s) (if any) should be placed in the end of the paper before References and typed in 10 pt Times regular, full justified, with the title as unnumbered second level heading.

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